

Westinghouse Non-Proprietary Class 3

LTR-NRC-06-57 NP-Attachment

**Draft Slide Presentation for the POLCA-T Topical Report
Pre-Submittal Meeting (Non-Proprietary)**

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Westinghouse Non-Proprietary Class 3

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POLCA-T NRC Licensing: Code Description

NRC/Westinghouse Meeting
Rockville, Maryland
November, 2006

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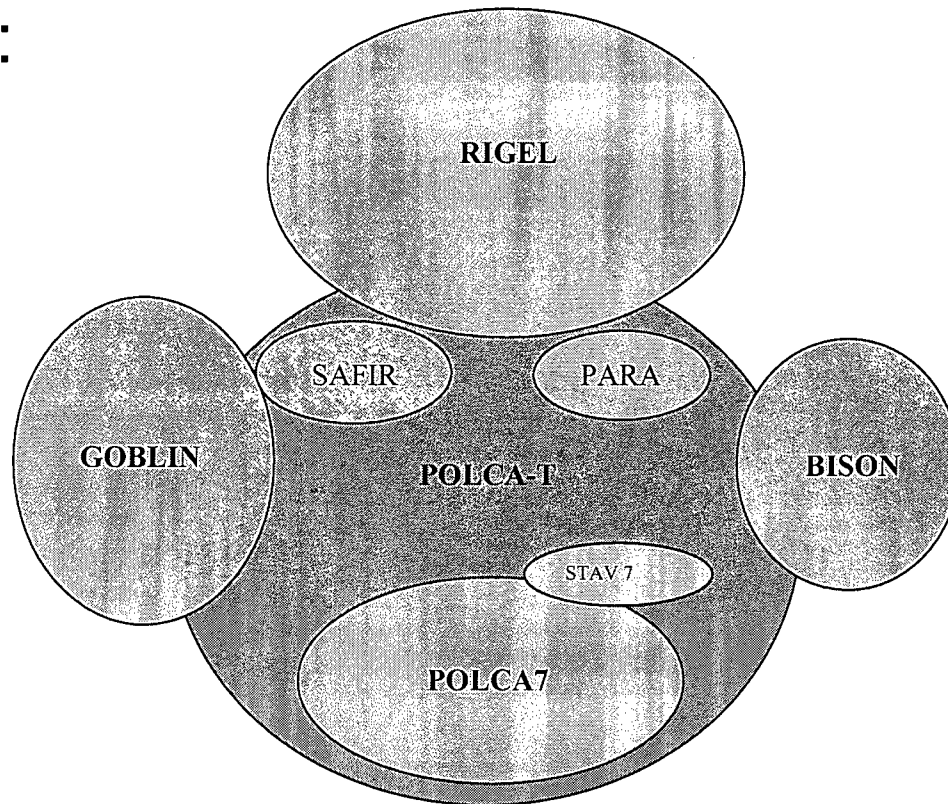
Content

- Code Structure
- Overall Model Formulation
- Hydrodynamic Model
- Reactor Kinetics Model
- Constitutive Models
- Heat Structure Models
- Fuel Rod Model
- Component Models
- Basic Solution Method
- Example from validation base
- Conclusion

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Code Structure

- The POLCA-T code is based to an extent on the following codes:



Code Structure

- Bases for POLCA-T

<u>Code</u>	<u>Application area</u>	<u>Feature used in POLCA-T</u>
– RIGEL	Transients and LOCA	Design
– GOBLIN	BWR LOCA & plant simulation	Num Method
– POLCA7	Static Core Design	Neutron Kinetics
– BISON	BWR Transients	Specific models
– STAV7	Fuel rod simulation	Fuel Rod Equ.
– PARA	Steam line models	As it is

All codes are USNRC licensed except the RIGEL code

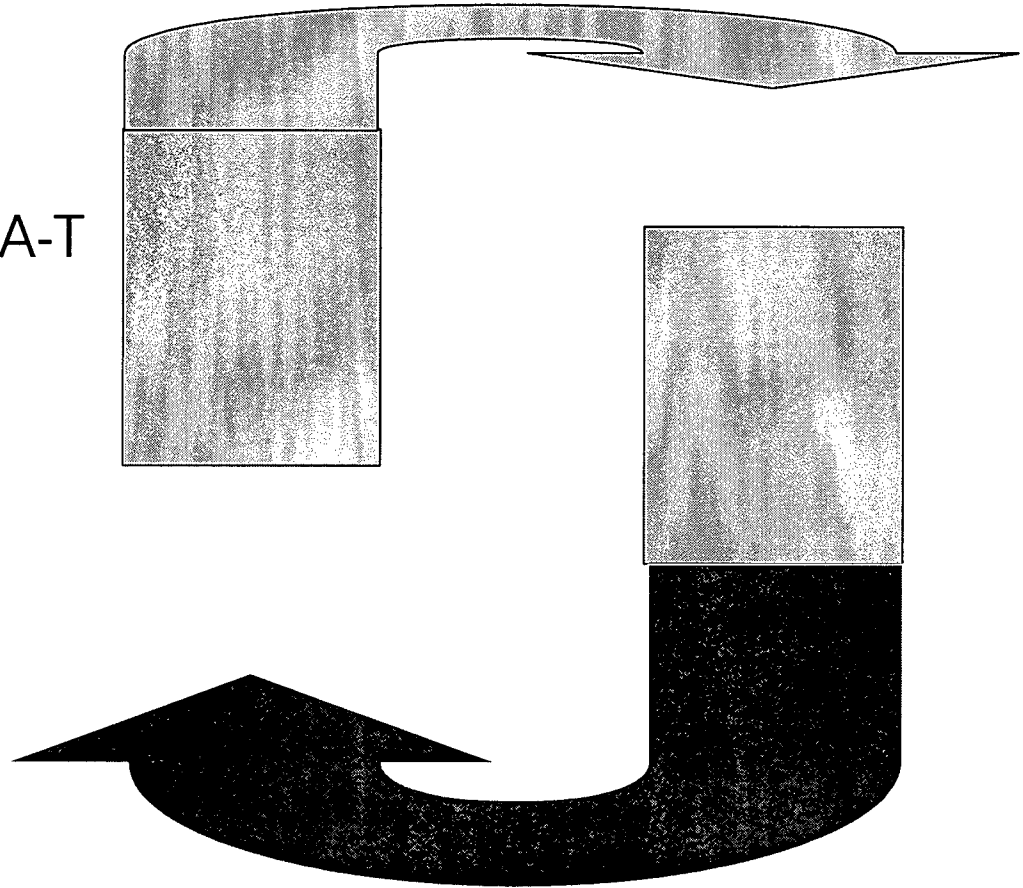
Code Structure

- Computational procedure
 - POLCA7 3D neutronics calculation
 - POLCA-T calculation
 - core and system T/H response, all assemblies and bypass
 - fuel temperature

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Code Structure

- Interaction between POLCA-T and POLCA7 codes



Overall Model Formulation

- Methods and Formulation

- Thermal-Hydraulics:

- Five-equations formulation
 - mass balance (2 eq)
 - energy balance (2 eq)
 - momentum balance (1 eq)
 - Drift flux relation or CCFL-relation (1 eq)
 - Average volume cell velocities (2 eq)

- Boron mass transport

- Non condensable gas mass balance

- Heat structure:

- finite difference formulation

- 1D conduction

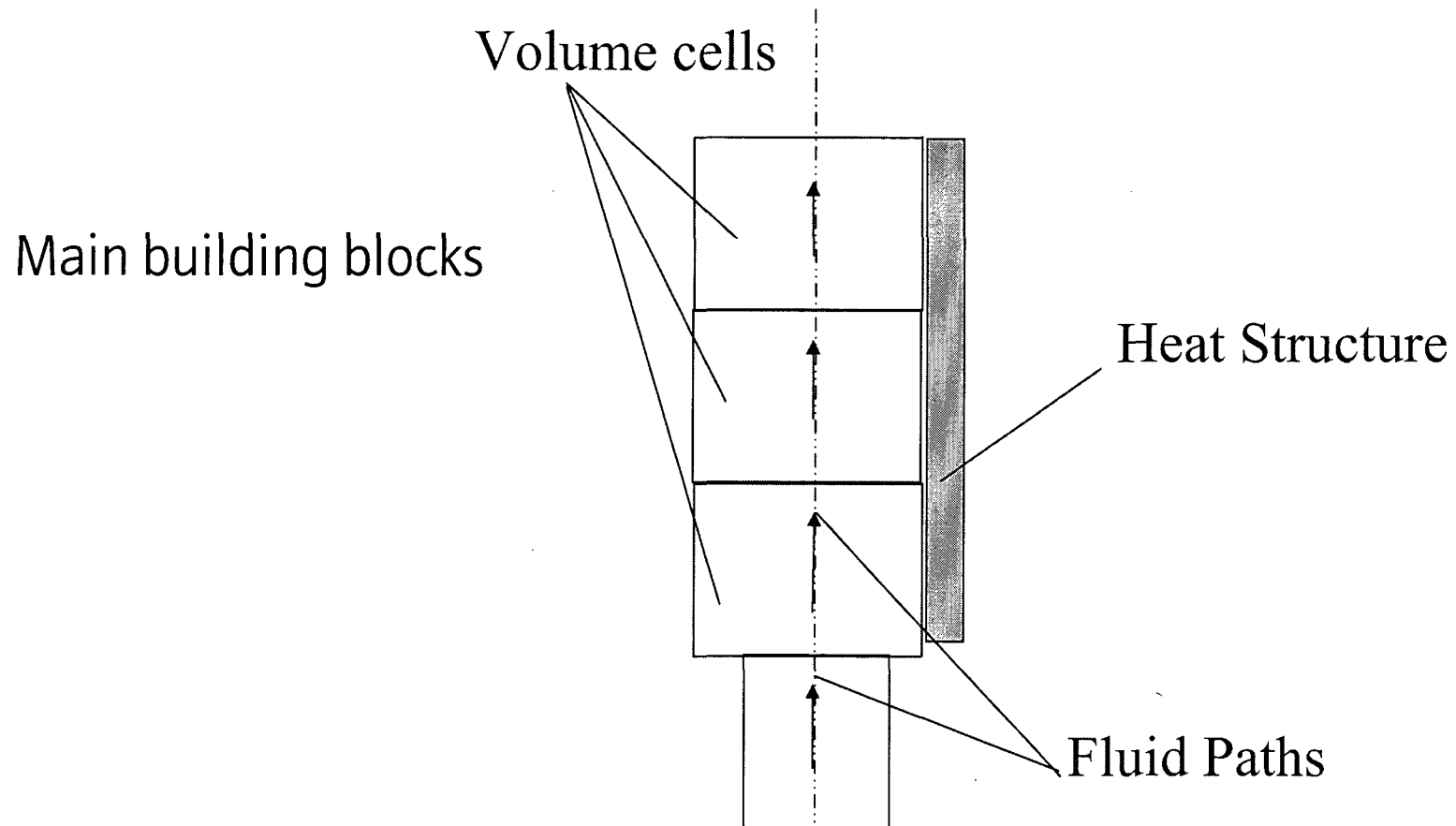
- HTC by correlations

Overall Model Formulation

- Building blocks
 - Volume cells
 - Flow paths
 - Heat structures
 - Heat generation
 - Components
 - Special phenomena
- Features
 - BWR or PWR
 - Non nuclear systems
 - Free modeling
 - Different fuel types
 - Virtually no limits in cells, heat structures, number of pumps, etc

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Overall Model Formulation

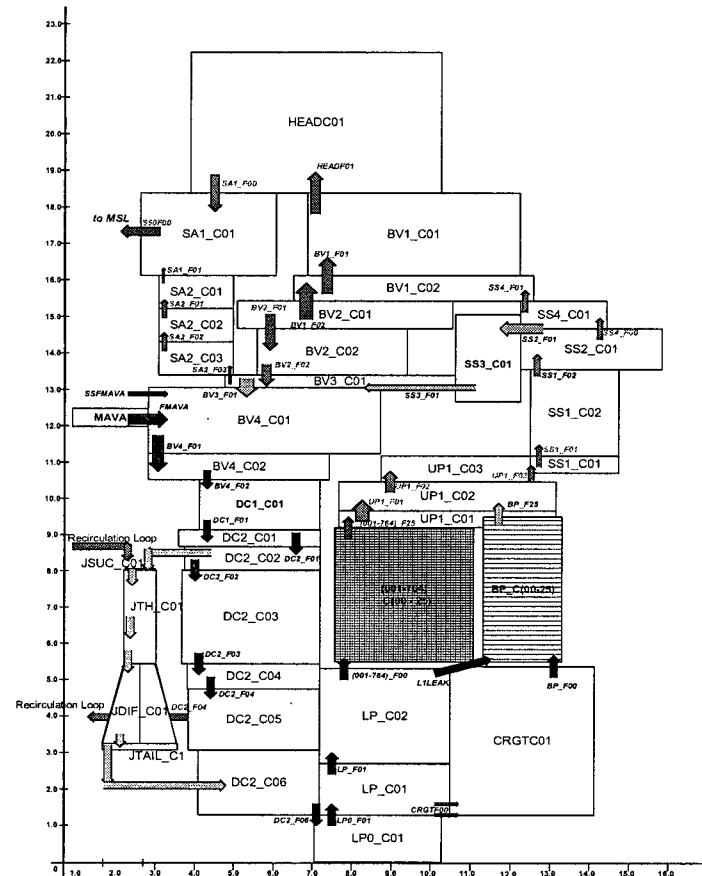


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Overall Model Formulation

Typical reactor model with
internal parts , jet
pumps, core and
pressure vessel

The entire core is imported
automatically from
POLCA7



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Hydrodynamic Model

- Primary variables:

volume cells

a, c

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Hydrodynamic Model

- POLCA-T Primary Variables

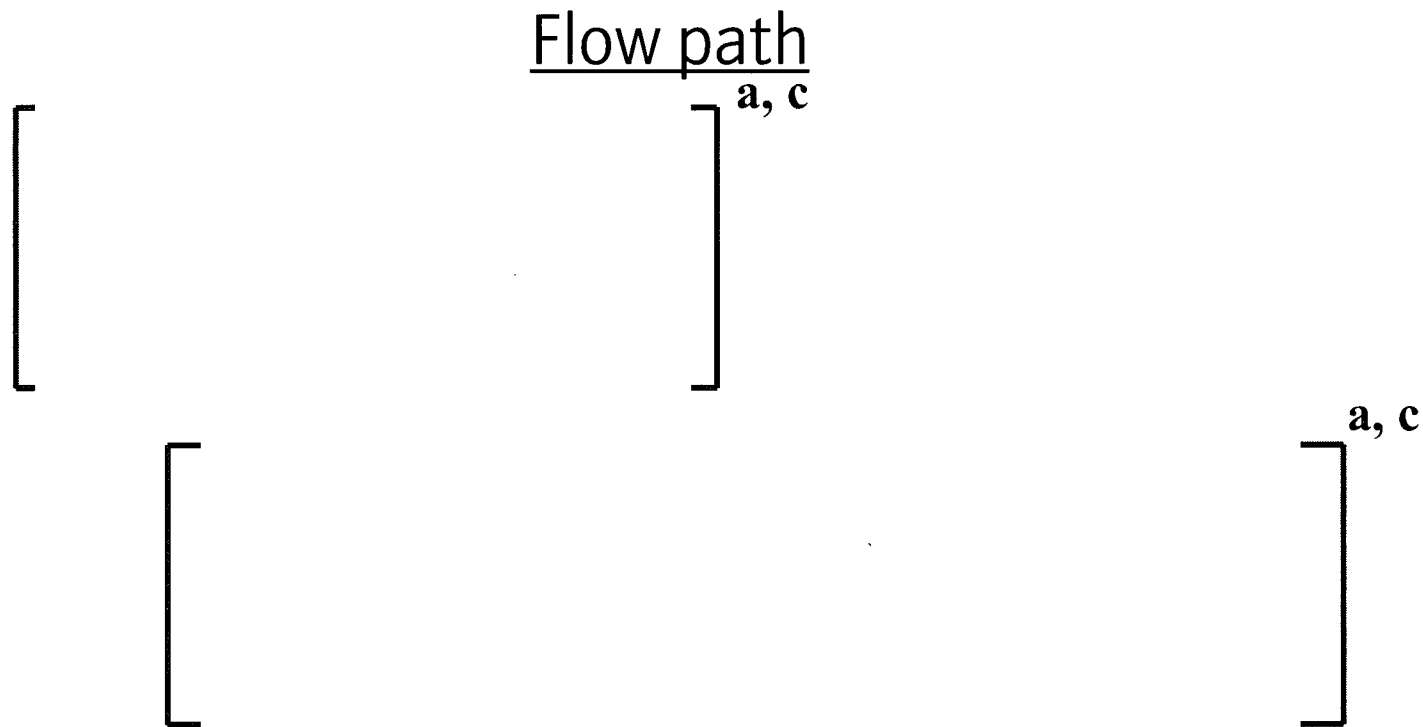
Volume
cell

a, c

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Hydrodynamic Model

- Primary variables:



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Reactor Kinetics Model

- Nuclear kinetics
 - 3D kinetics
 - POLCA7:
 - Two groups model
 - Analytical Nodal Method
 - Iteration scheme
 - Axial homogenization model
 - Reflector model
 - Cross Section model
 - Depletion models

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Reactor Kinetics Model

- Numerical method
 - NEU3
 - Standard 2-group Analytic Nodal Method (ANM) with quadratic transverse leakage approximation
 - Default method for both BWR & PWR

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Constitutive Models

- Pressure losses
 - Colebrook or can opt for other correlations
 - Singular losses Re dependent
 - Other fuel dependent correlations

Constitutive Models

- Drift Flux Equation
 - The sixth equation

$$F_{drift} = u_{liq} \cdot S + u_{rel} - u_{gas}$$

- Drift Flux Models
 - Holmes type model
 - DF02 model

Constitutive Models

- Drift flux model of Holmes type
 - The slip

$$S(\alpha, p) = \frac{u_g}{u_l} = \frac{1 - \alpha}{\frac{1}{C_0} - \alpha}$$

- The relative velocity

$$u_r(\alpha, p) = \frac{C_0 K_u V_c}{1 - \alpha C_0 \left(1 - \sqrt{\frac{\rho_g}{\rho_l}} \right)}$$

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Constitutive Models

- Drift flux model of DF02 type

a, c

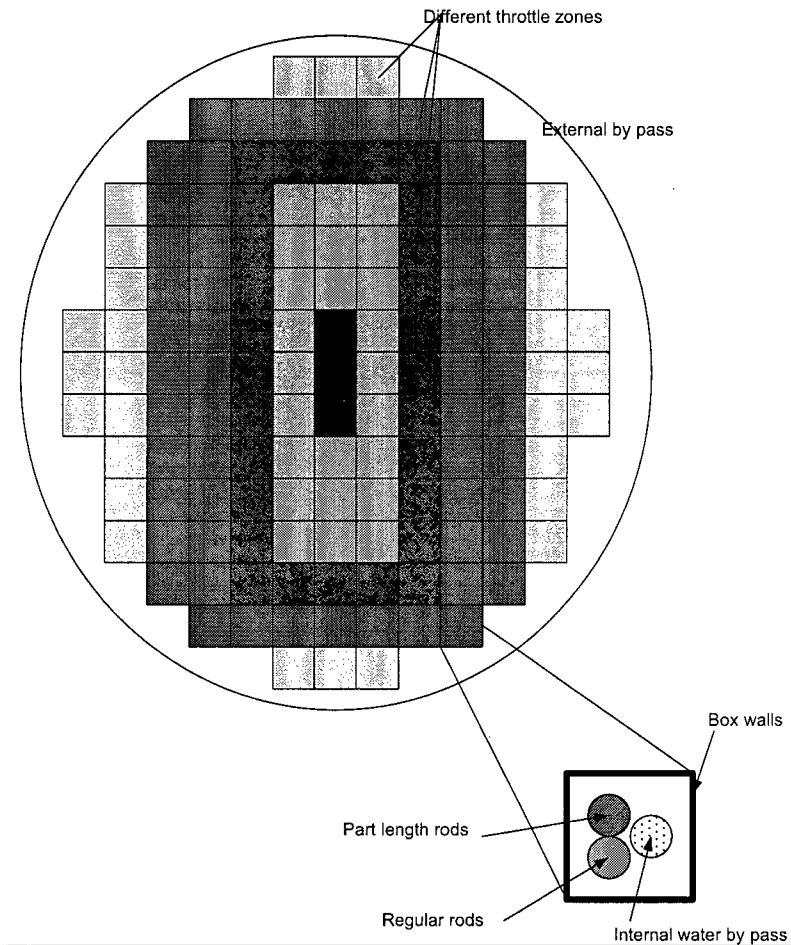
Heat Structure Models

- Heat structures
 - SLABS or RODS or CYLINDRICAL GEOMETRY
 - 1 D conduction
 - User-specified properties versus temperature
 - User-specified power distribution
 - HTC correlations

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Heat Structure Models

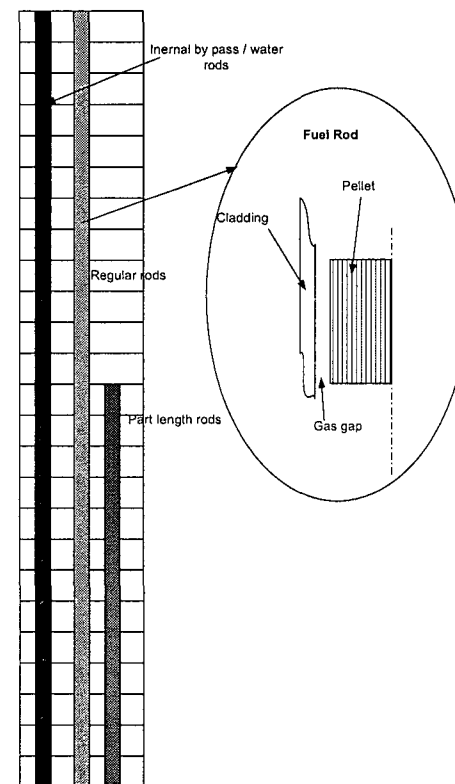
- Modeling of the core
 - Imported from POLCA7, static simulation
 - All assemblies, can take advantage of symmetry
 - Inter assembly bypass
 - Outer bypass



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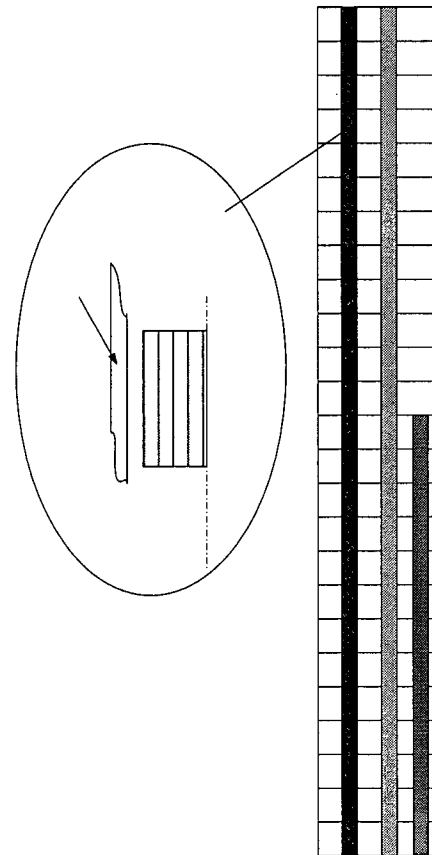
Heat Structure Models

- Modeling of the fuel assembly with fuel rods
 - Boxes, cross and wings
 - Internal bypass
 - Leakage flows
 - Part length rods mixed with full length
 - Water rods



Fuel Rod Model

- Fuel rods
 - as regular heat structures
 - pellet, gas gap & cladding
 - dynamic gas gap
 - radial power distribution within the pellets
 - fission gas release



Component Models

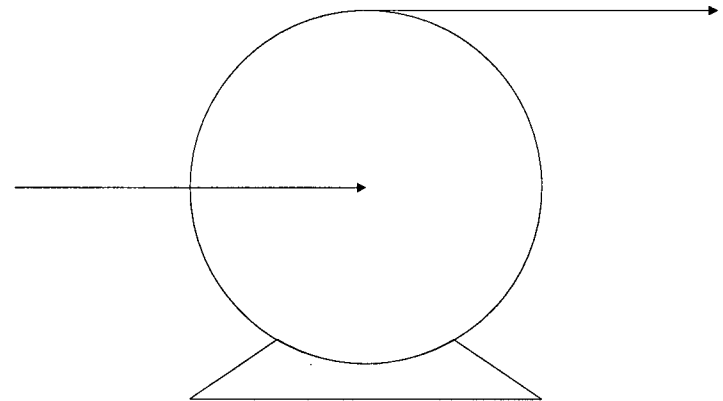
- Pumps
 - Centrifugal pumps
 - Jet pumps

- Drives
 - Electrical motors

- Valves
 - Safety relief valves
 - Check valves

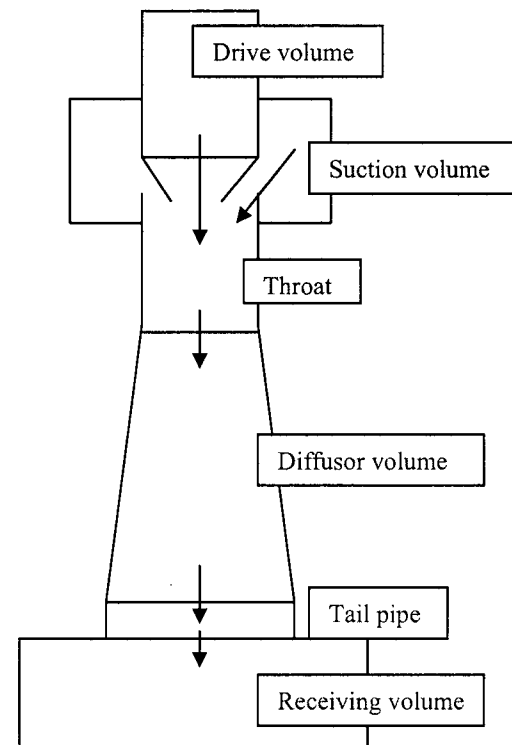
Component Models

- Centrifugal pumps
 - based on homological curves for pressure head, volume flow rate, and torque
 - torque balance equation for the shaft to the drive
 - can be added elsewhere in the model
 - friction at rest



Component Models

- Jet pump
 - created from the building blocks
 - can have many pumps
 - drive pump is a centrifugal pump



Basic Solution Method

- General equation for POLCA-T

is :

$$F_{tr} \sum_{u=1}^{m_k} h_{uk}(\mathbf{y}) \frac{d(g_{uk}(\mathbf{y}))}{dt} = f_k(\mathbf{y})$$

$$F_{tr} = 0 \quad (\text{steady state})$$

$$F_{tr} = 1 \quad (\text{transient conditions})$$

$$\mathbf{y}_k^{t+1} = \mathbf{y}_k^t + \Delta t \cdot \dot{\mathbf{y}}_k$$

Basic Solution Method

- Equation solver
 - Direct solver MA-28 used in POLCA-T (T/H)-part
 - Developed for large, sparse unsymmetrical system
 - First step, MA28A, strategy & stability determination of complete partitioning
 - Second step, MA28B, factorization and elimination
 - Third step, MA28C, back substitution , i.e. solving for actual right hand side

Basic Solution Method

Same formulation both in steady state as
in transient calculation, example:

—In steady state:





$$F_{\text{TR}} = 0, \Theta_f = 1., \Theta_h = 1 \text{ and } \Delta t = 1.$$

$$\sum_{j=1}^n -\frac{\partial f_k}{\partial y_j} \Delta y_j = f_k^{n+1,r}$$








$$y_j^{i+1} = y_j^i + \Delta y_j$$

Example from Validation Base

- Analytical solutions:






- Oscillations in U-tube 
- Incompressible flow 
- Compressible flow 
- Gravity driven flow 
- ...

- Separate effects:




- INEL jet pump tests 
- Steam separator tests 
- FRIGG void 
- FRIGG pressure drop 
- FIX II Post Dryout 
- FRIGG dryout 
- []^{a, c} channel flow
- RIA SPERT III E-Core 
- ...

Example from Validation Base


● Integral tests, stability:

- []^{a, c} 
- []^{a, c} 
- []^{a, c} 
- []^{a, c} 
- []^{a, c} 
- ...

● Integral tests, transients :

- []^{a, c} TT 
- []^{a, c} pump trip 
- []^{a, c} pancake core 
- ...

● Integral tests, static:

- Benchmark vs POLCA7 
- []^{a, c} Start-up sequence
- []^{a, c} Core follow
- ...

Conclusion

- The code is based on well established codes such as GOBLIN, BISON , POLCA7
- An evolution from older codes above with modern design
- The code is very general and flexible
- The code has a large validation base
- Validation base covers transients, stability, separate effects

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POLCA-T NRC Licensing: Control Rod Drop Accident Application

NRC/Westinghouse Meeting
Rockville, Maryland
November, 2006

Outline

Contents of Topical Report:

1. Summary and Conclusions
2. Control Rod Drop Accident (CRDA) Model Requirements
3. Assessment Data Base
4. Westinghouse BWR CRDA Analysis Methodology
5. Evaluation Model Assessment
- Appendices

Outline (cont.)

Contents of Topical Report (cont):

- **Appendices**

1. Qualification against NEACRP 3-D LWR Core Transient Benchmark
2. Qualification against []^{a,c} End of Cycle 2 Turbine Trip Tests
3. Qualification against SPERT-III-E Core Experiments
4. POLCA-T Comparison with RAMONA

1. Summary and Conclusions (cont.)

1. Scope

- Describes Westinghouse BWR CRDA Methodology
- Provides qualification information
- Demonstrates that the methodology is adequate for ensuring compliance to GDC 28 and SRP (NUREG-0800)
- Westinghouse methodology for performing CRDA analyses and the systematic cycle-specific analysis strategy

2. Objectives

- Identify specific design bases which, if satisfied, assure that all requirements specified in GDC 28 and NUREG-0800 applicable to the CRDA are satisfied
- Apply up-to-date methods and models
- Decrease conservative unjustified assumptions

1. Summary and Conclusions (cont.)

3. Conclusions

- The design bases identified are sufficient to assure that all requirements and guidelines identified in the GDC and NUREG-0800 for the CRDA will be satisfied
- The methodology and strategies described are acceptable for design and licensing purposes, i.e. for identifying the limiting event and evaluating BWR plant response and subsequent consequences to the fuel systems
- The methodology can be used to analyze CRDA for variety of core and control rod designs

2. CRDA Model Requirements

- The event can occur in any reactor operating state
 - Consideration to all the CR configurations in normal operation
 - CR configurations can result of equipment malfunction or operator error
- Most unfavorable conditions:
 - At low or zero power conditions
 - CR patterns that provide the highest values of incremental single CR worth
 - Strongly subcooled conditions (start-up from cold shut down)

2. CRDA Model Requirements (cont.)

- Plant specific: hardware employed for rod sequence control and the technical specifications concerning inoperable rods in order to determine the limiting incremental rod worth
 - Banked Position Withdrawal Sequence (BPWS) plants: Rod Worth Minimizer used below a specified power (typically 5 to 20 %) to enforce the rod withdrawal sequence
 - Group Notch class of plants: a group notch Rod Sequence Control System (RSCS) is installed to control the sequence of rod withdrawal
 - For GE-built BWR/6 plants a Rod Pattern Control System (RPCS) is used to enforce BPWS rules

2 CRDA Model Requirements (cont.)

1. Accident Description

- Fully inserted CR becomes decoupled from its drive and sticks in the fully inserted position
- The rod is assumed to drop at the time when under critical reactor conditions, a rod pattern exists for which the decoupled rod has the maximum incremental worth
- The reactor goes on a positive period, and the initial power burst is terminated by the fuel temperature reactivity feedback
- The 120% APRM power signal scram occurs (no credit is taken for the Intermediate Range Monitor or set-down APRM scram)
- All withdrawn rods, except the decoupled rod, scram at the technical specification rate
- A scram terminates the accident

2. CRDA Model Requirements (cont.)

2. Current Analysis Method
 - NRC-approved CENPD-284-P-A, July 1996, RAMONA-3B
3. Design Basis selected to be in compliance with
 - GDC 28 (10CFR 50, Appendix A)
 - SRP 15.4.9 and 15.4.9A (NUREG-0800)
4. Parameter Sensitivities – PIRT Tables
 - PIRT Tables based on NUREG/CR-6742 and NUREG/CR-1749
 - POLCA-T performed sensitivity studies

3. Assessment Data Base:

POLCA-T Qualification for CRDA Analysis

1. Qualification against NEACRP 3-D LWR Core Transient Benchmark
2. Qualification against []^{a,c} End of Cycle 2 Turbine Trip Tests
3. Qualification against SPERT-III-E Core Experiments
4. Nuclear Heating Event []^{a,c} in 2000
5. POLCA-T Comparison with RAMONA-3B

3.1 POLCA-T NEACRP 3-D LWR Benchmark

Benchmark specifications:

- PWR Rod Ejection Accident
- Westinghouse 3-loop core with 157 fuel assemblies
- Core loading pattern is a typical first core checker-board
- Three batches of fuel assemblies using burnable absorbers
- Six Problems:

Case	Geometry	Initial state	Ejected Rod
A1	octant	HZP	central
A2	octant	HFP	central
B1	octant	HZP	peripheral
B2	octant	HFP	peripheral
C1	full core	HZP	peripheral
C2	full core	HFP	peripheral

POLCA-T (POLCA/RIGEL) Analysis:

- Problems A1 and C1: HZP = 2775 W
- Problems A2 and C2: HFP = 2775 MW
- Core radially surrounded by one layer of 64 reflector assemblies
- The top and bottom 30 cm thick axial reflectors
- One or four radial node(s) per fuel assembly – 1x1, 2x2;
- 16 axial nodes
- Heat conduction equation in fuel in 8 annular zones

Reference solutions provided by Nuclear Energy PANTHER code: solves two-group homogeneous neutron diffusion equations in both steady-state or transient form using an analytical nodal method, generalized thermal-hydraulics feedback model for PWR.

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3.1 POLCA-T NEACRP 3-D LWR Benchmark

POLCA-T Results and Comparison with PANTHER reference results

Parameter		Code						
		POLCA/RIGEL		PANTHER				
	Nodes	1x1	2x2	2x2	1x1	2x2	4x4	8x8
	Case			First	Revised			
Max power, %	A1	112.0	143.0	117.9	89.2	121.4	124.9	125.2
	A2	107.4	107.5	108.0	107.7	108.0	108.0	107.9
	C1	628.0	560.0	477.3	547.1	497.3	491.3	n.a.
	C2	106.9	106.8	107.1	107.2	107.1	107.1	n.a.
Time of max power, s	A1	0.590	0.550	0.560	0.556	0.560	0.233	0.553
	A2	0.100	0.100	0.100	0.100	0.100	0.100	0.100
	C1	0.250	0.270	0.268	0.263	0.270	0.270	n.a.
	C2	0.100	0.100	0.100	0.100	0.100	0.100	n.a.
Final values at 5 sec								
Power, %	A1	20.1	20.3	19.6	19.6	19.6	19.3	19.4
Core average Doppler Temperature, °C	A1	321.7	322.5	324.3	323.9	324.5	324.3	324.2
Coolant Outlet Temperature, °C	A1	292.9	293.0	293.1	293.0	293.1	293.1	293.0

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3.1 POLCA-T NEACRP 3-D LWR Benchmark

Conclusions:

- Good agreement with PANTHER reference result
- Conservative power predictions
- Accurate fuel and kinetics models

3.2. POLCA-T []^{a, c} EOC 2 Turbine Trip Tests

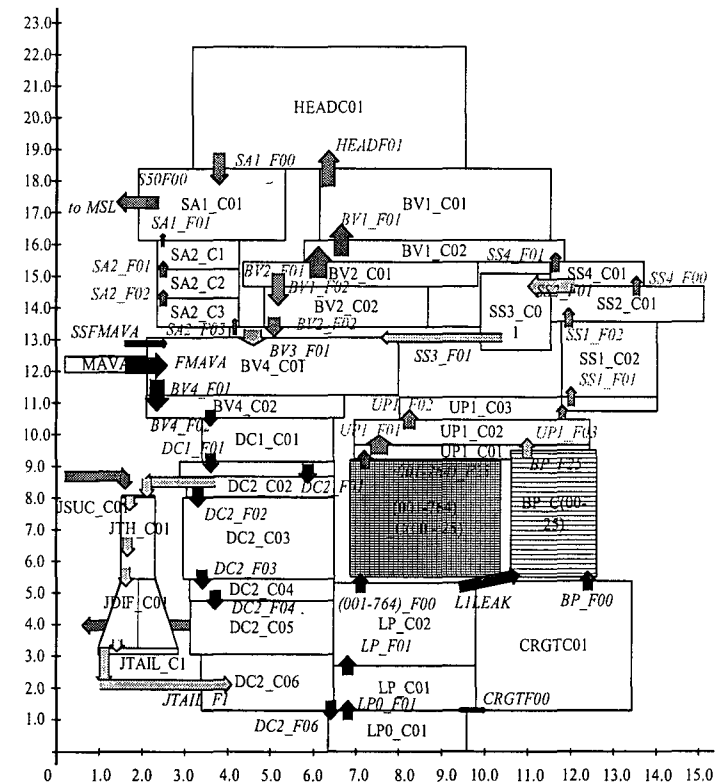
Very Fast Transient with the same time scale as CRDA, validates thermal-hydraulics and kinetics models

OECD/NRC BWR turbine trip (TT) benchmark

- All Exercises 1, 2, 3
- Best Estimate Scenario and
- Four Extreme Scenarios

[]^{a, c} EOC2 TT1, TT2, and TT3 tests

- No benchmark limitations
- PHOENIX XS
- POLCA7 core follow
- POLCA-T models
- Sensitivity Studies
- TIP and LPRM comparison



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3.2. POLCA-T []^{a, c} EOC 2 Turbine Trip Tests

a,b,c

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3.2. POLCA-T []^{a, c} EOC 2 Turbine Trip Tests

a,b,c



3.2. POLCA-T []^{a,c} EOC 2 Turbine Trip Tests

Conclusions:

D/NRC BWR turbine trip (TT) benchmark

- All Exercises 1, 2, 3.
- Best Estimate Scenario and
- Local power

Very Fast Transient with the same time scale as CRDA, validates thermal-hydraulics and kinetics models []^{a,c} EOC2 TT1, TT2, and TT3 tests

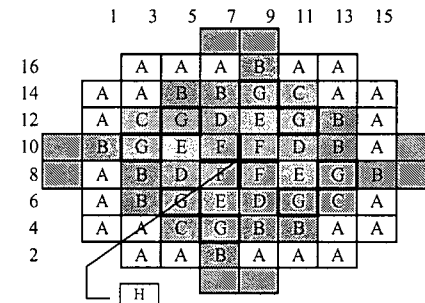
- No benchmark limitations
- PHOENIX XS
- POLCA7 core follow
- POLCA-T models
- Sensitivity Studies
- TIP and LPRM comparison

3.3. POLCA-T SPERT-III-E Core Experiments

SPERT-III-E Core

- PWR fuel design with boxes
- BWR cruciform transient CR
- Stationary CR Fuel followers with unknown positions
- Small reactor $\sim 1 \times 1 \times 1$ m
- Very high neutron leakage
- Non-commercial reactor: very special set-up
- Very high measurements uncertainty

Difficult to model and hard to draw conclusions



- A: 25-rod assembly
- B: 25-rod assembly adjacent to 16-rod assembly with Control Rod (G)
- C: 25-rod assembly adjacent to two 16-rod assemblies with Control Rod (G)
- D: 25-rod assembly adjacent to 16-rod assembly with Control Rod (G) and 16-rod assembly (F)
- E: 25-rod assembly adjacent to two 16-rod assemblies with Control Rod (G) and 16-rod assembly (F)
- F: 16-rod assembly
- G: 16-rod assembly with Control Rod
- H: Transient Rod
- Empty position

PHOENIX4/POLCA7/POLCA-T code package

- Special NGET procedure for radial reflector XS and axial boundaries data and PHOENIX4/POLCA7 color set calculations
- Steady states adjusted
- No transient adjustments

Six cases analyzed:

- Four CZP: 18, 22, 43, 49
- Two HZP: 32, 62

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3.3. POLCA-T SPERT-III-E Core Experiments

a,b,c



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3.4. POLCA-T Comparison with RAMONA-3B

a,b,c



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4. Westinghouse BWR CRDA Analysis Methodology

- Two Step Methodology

a,b,c



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4. Westinghouse BWR CRDA Analysis Methodology

1. Introduction (Evaluation Model)
2. Overview

a, c

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5. Evaluation Model Assessment

a, c



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Conclusions

a, c



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POLCA-T NRC Licensing: Stability Applications

NRC/Westinghouse Meeting
Rockville, Maryland
November, 2006

- Introduction

- Background

- []^{a, c}
- []^{a, c}
- []^{a, c}

- Measurements and calculations

- []^{a, c}
- Uncertainty analysis
- Comparison of measured and calculated data

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Outline

- Introduction
- Background
- Measurements and calculations
- Sensitivity study
- Methodology
- Concluding remarks

Introduction

- US: no measurements / Europe: regular measurements
- Different purposes for measurements
 - Confirmation of stability characteristics in connection with power uprates and introduction of new fuel designs
 - Confirmation of pre-calculations
- Different methodology for measurements
 - Noise evaluation (stable conditions)
 - Stability limit search

Introduction

- Different origin of requirements
 - Authorities
 - cycle specific
 - in connection with large changes
 - Local plant instructions

Background

[]^{a, c}

- ASEA Atom BWR-75 (1981)
- 2711 MW_{th}
- 676 fuel assemblies
- Uprate to 108% (1987)
- Cycle specific measurements (BOC, MOC)
 - Confirmation of pre-calculations
 - Defining exclusion region, partial scram
- C19 and C20 (2000-2002), 9 measurements

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Background

a, c



Background

[]^{a, c}

- ASEA Atom external pump design (1977)
- 2270 MW_{th}
- 648 fuel assemblies
- Uprate to 110% (1989)
- Cycle specific measurements
 - Confirmation of pre-calculations
- C14 – C17 (1990-1994), 40 measurements
- OECD/NEA benchmark

Background

[]^{a, c}

- GE BWR/6 (1984)
- 3138 MW_{th}
- 648 fuel assemblies
- Uprate to 112% (1996)
- Uprate to 115% (2002)
- Investigate stability characteristics
 - C7 (1990), verification of the stability monitor COSMOS
 - C10 (1993), mixed core characteristics

Background

- C13 (1999), power uprate program
- C19 (2002), power uprate program
- NACUSP (European Union)
- 16 measurements

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Background

a, b, c



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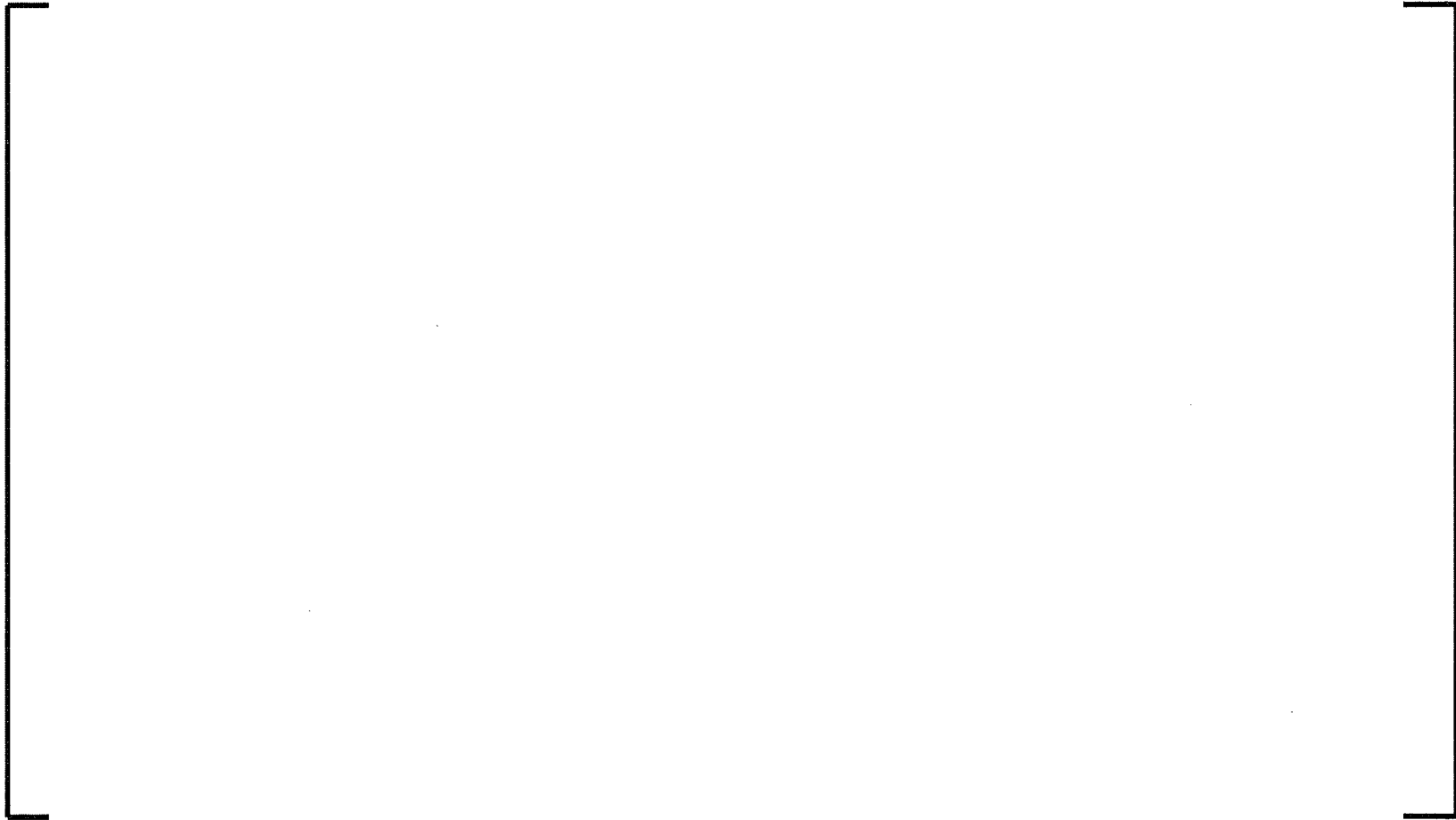
Measurements and calculations



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Measurements and calculations

a, b, c



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Measurements and calculations

a, b, c



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Measurements and calculations

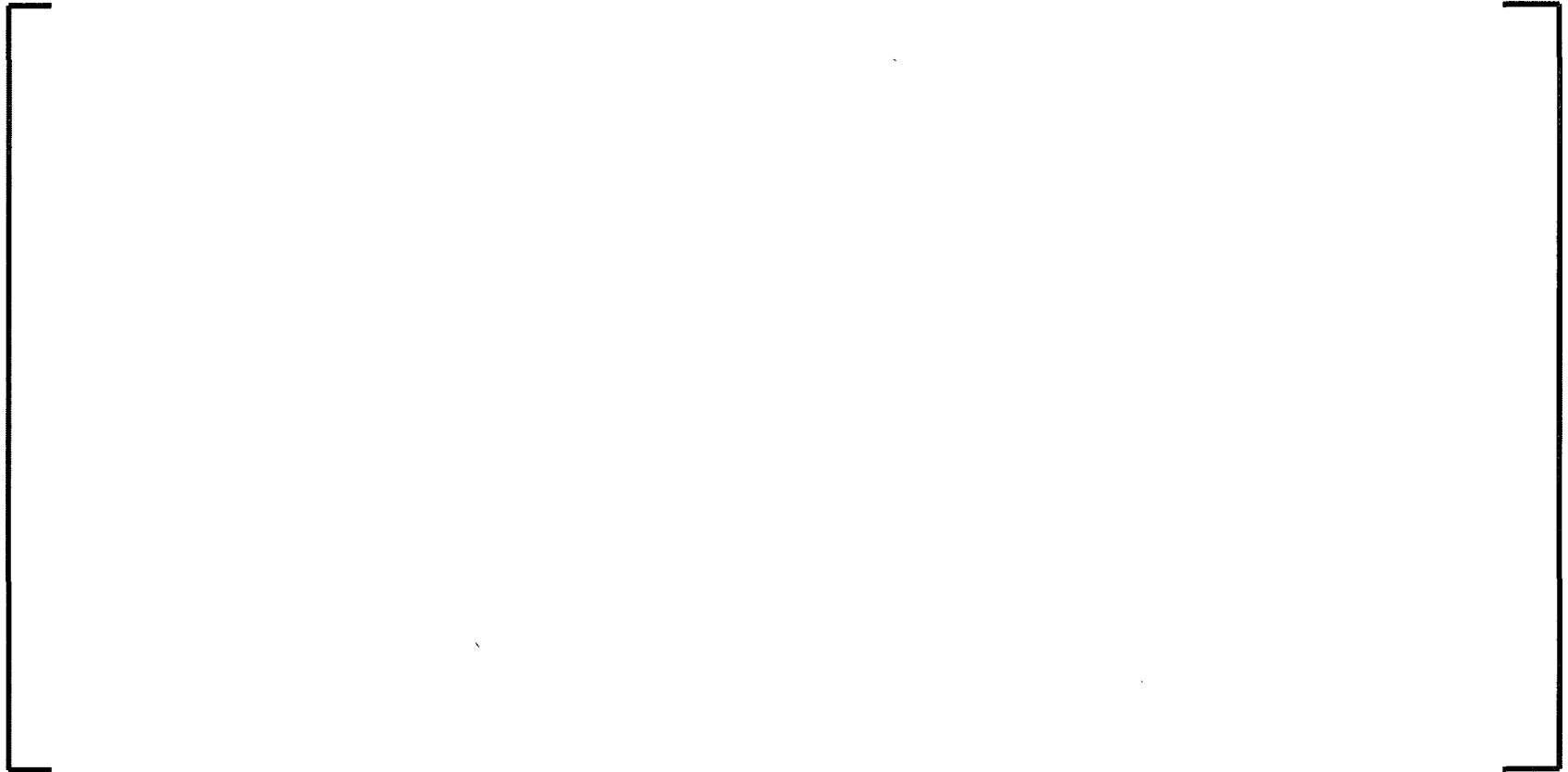
a, b, c



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Measurements and calculations

a, b, c



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Measurements and calculations

a, b, c



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Measurements and calculations

a, c



DRAFT

Measurements and calculations



a, c

DRAFT

Measurements and calculations

a, b, c



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Measurements and calculations

a, b, c



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Sensitivity study

a, c



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Sensitivity study

a, c



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Methodology

a, c

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Concluding remarks

[] a, c